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Gefen

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(54) **FOVEATED RETINAL PROSTHESIS**

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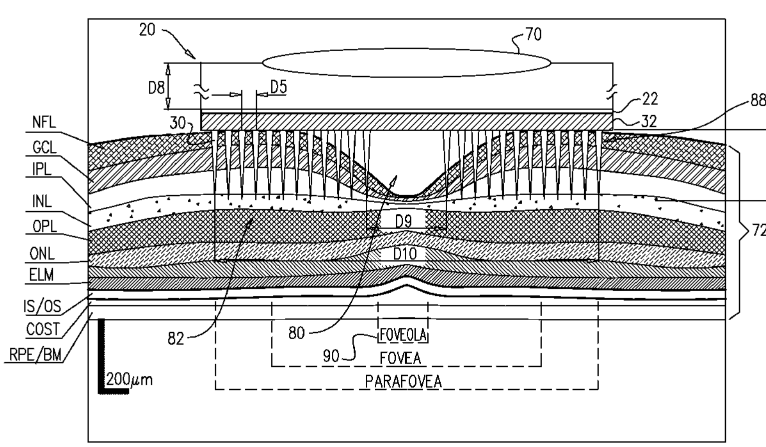
(57) **ABSTRACT**

Apparatus is provided having an intraocular device for implantation entirely in a subject's eye, the intraocular device including: a photosensor array having a plurality of photosensors, each photosensor detects ambient photons and generates a signal in response thereto. A spatial density of the photosensors in a central portion of the array is greater than a spatial density of the photosensors in an outer portion of the array. The intraocular device additionally includes a plurality of stimulating electrodes and driving circuitry coupled to the photosensors, and configured to drive the electrodes to apply electrical pulses to a retina of the eye in response to the signals from the photosensors. Other applications are also described.

6 Claims, 9 Drawing Sheets



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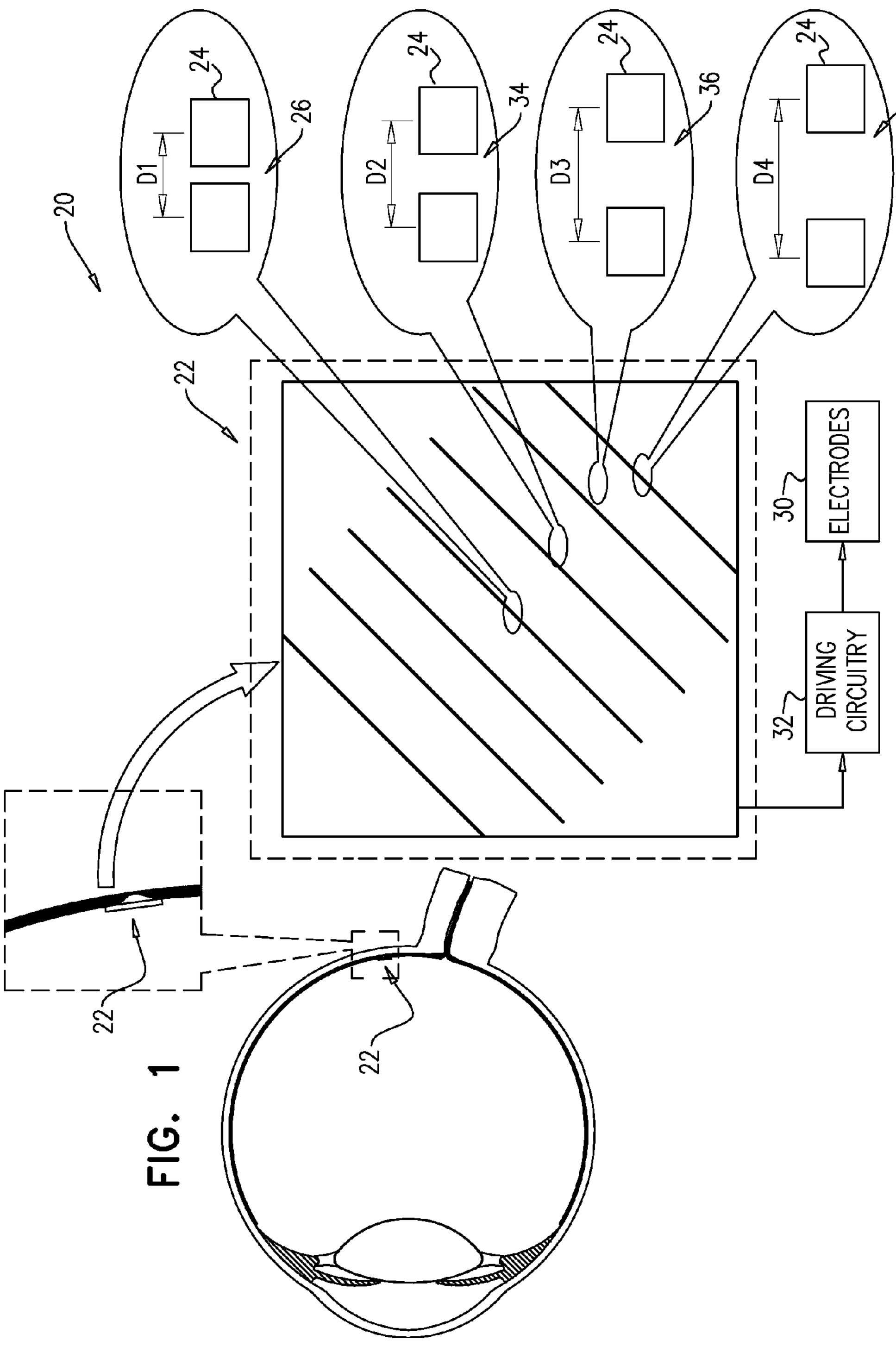
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22
22

FIG. 1

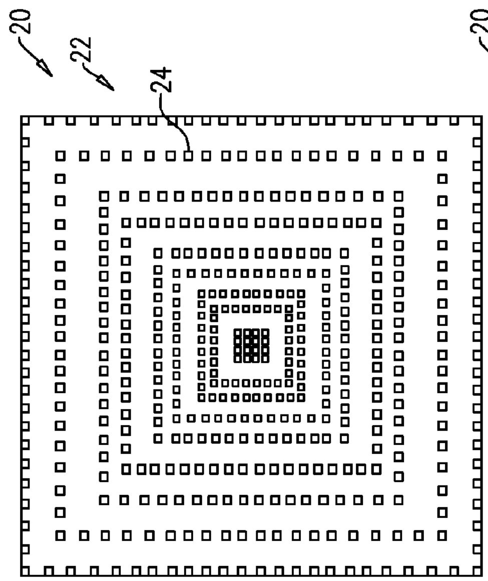

FIG. 2B

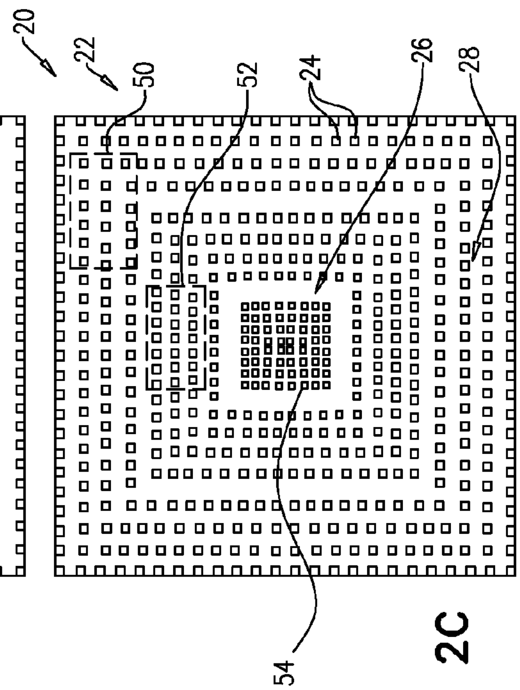

FIG. 2C

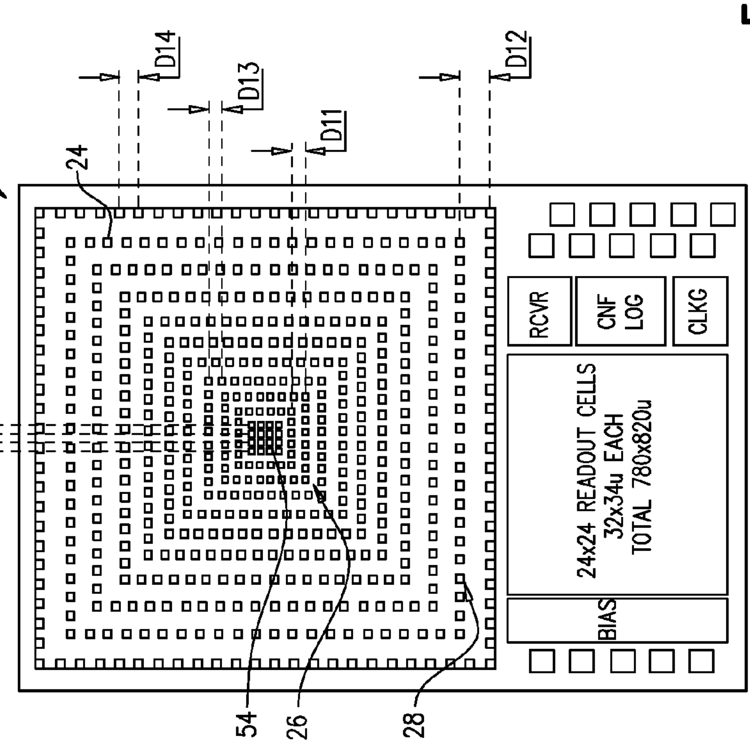

FIG. 2A

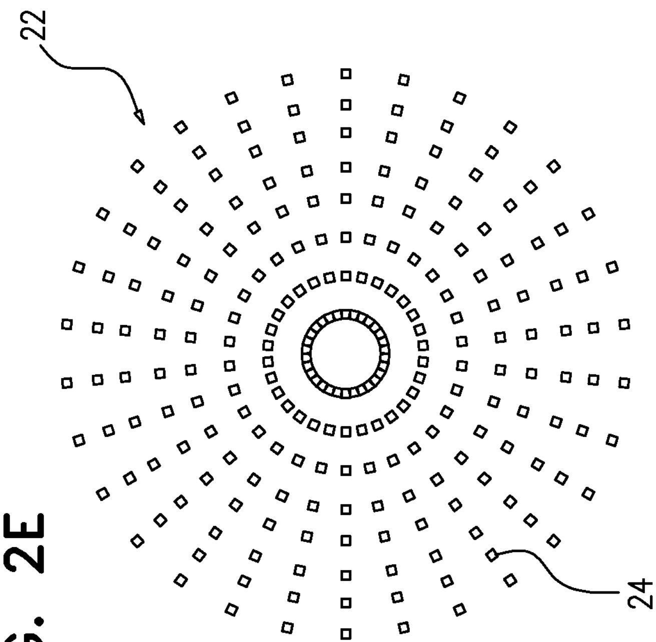

FIG. 2E

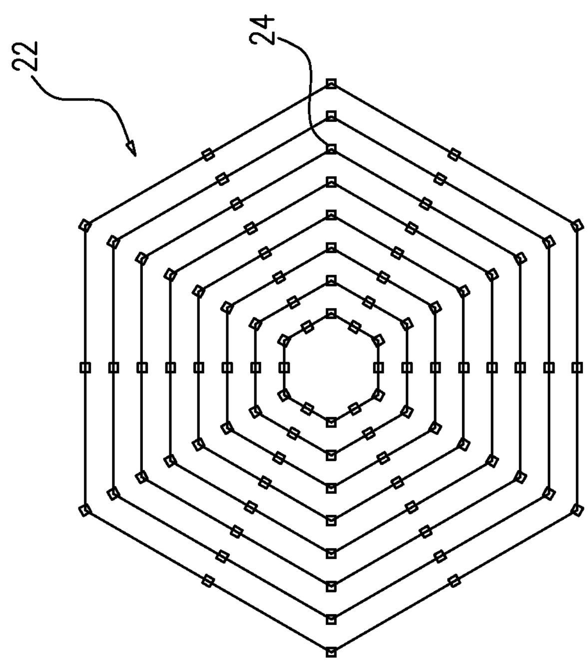

FIG. 2D

FIG. 3A

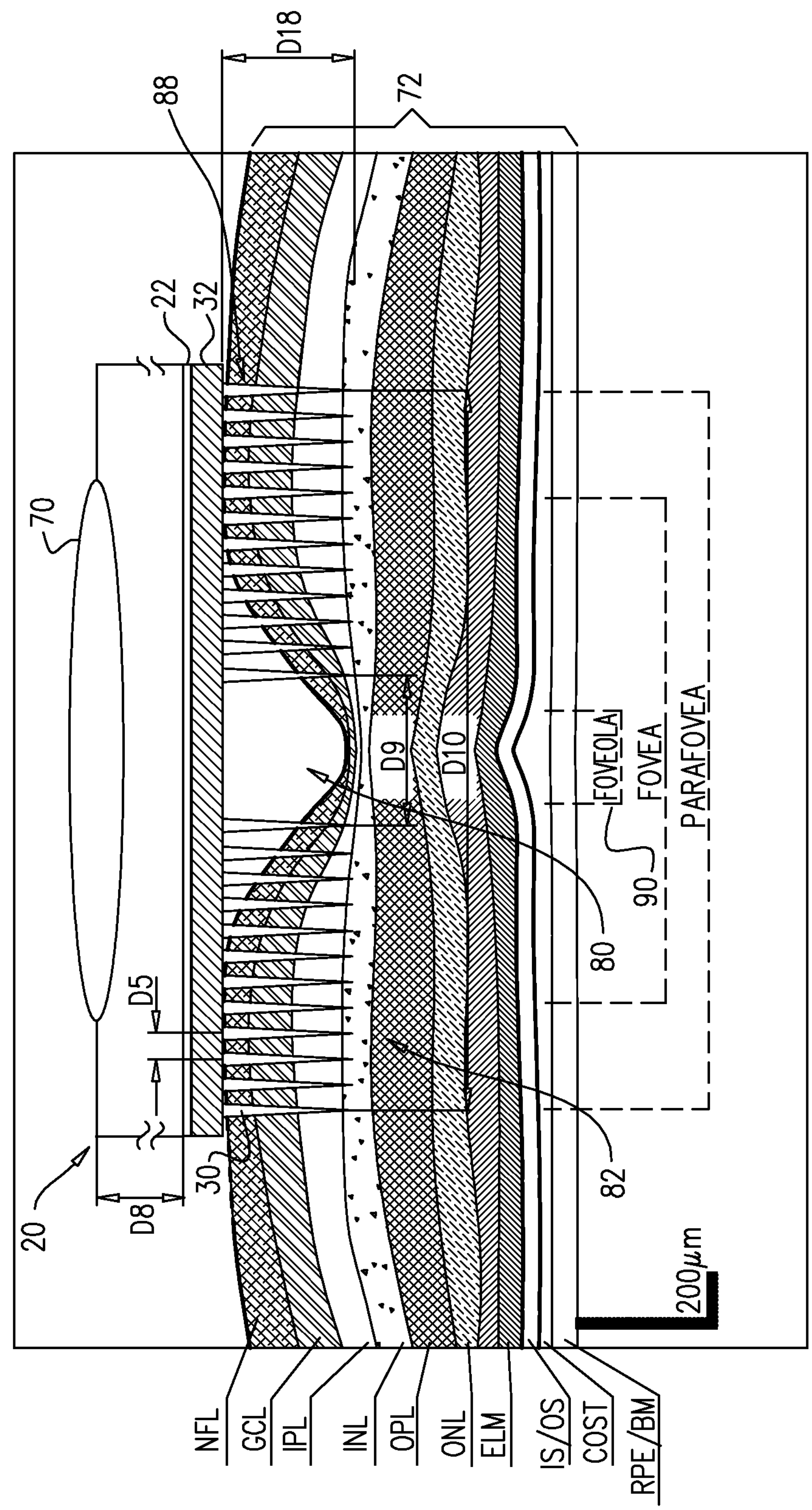

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FIG. 3B

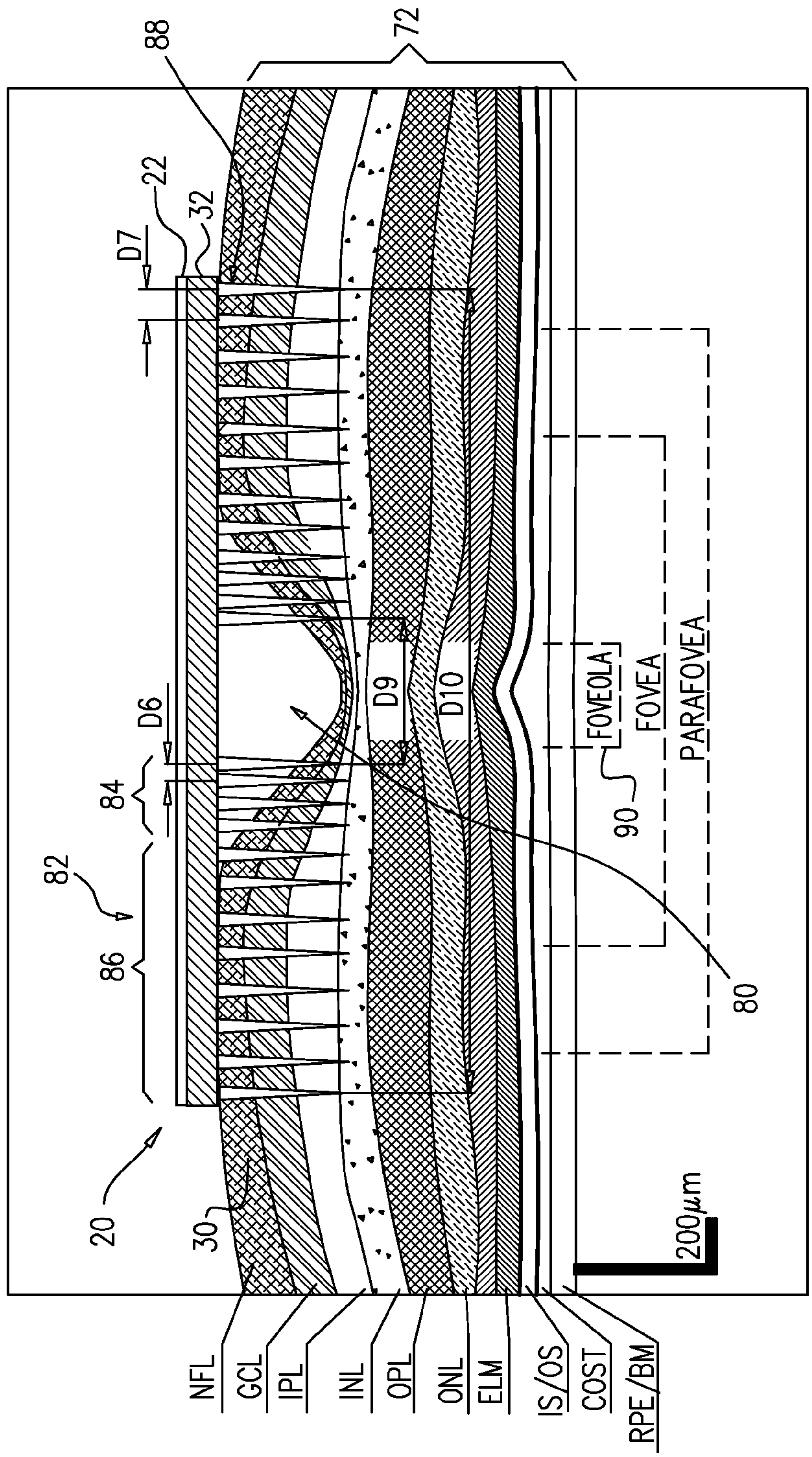
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FIG. 4A

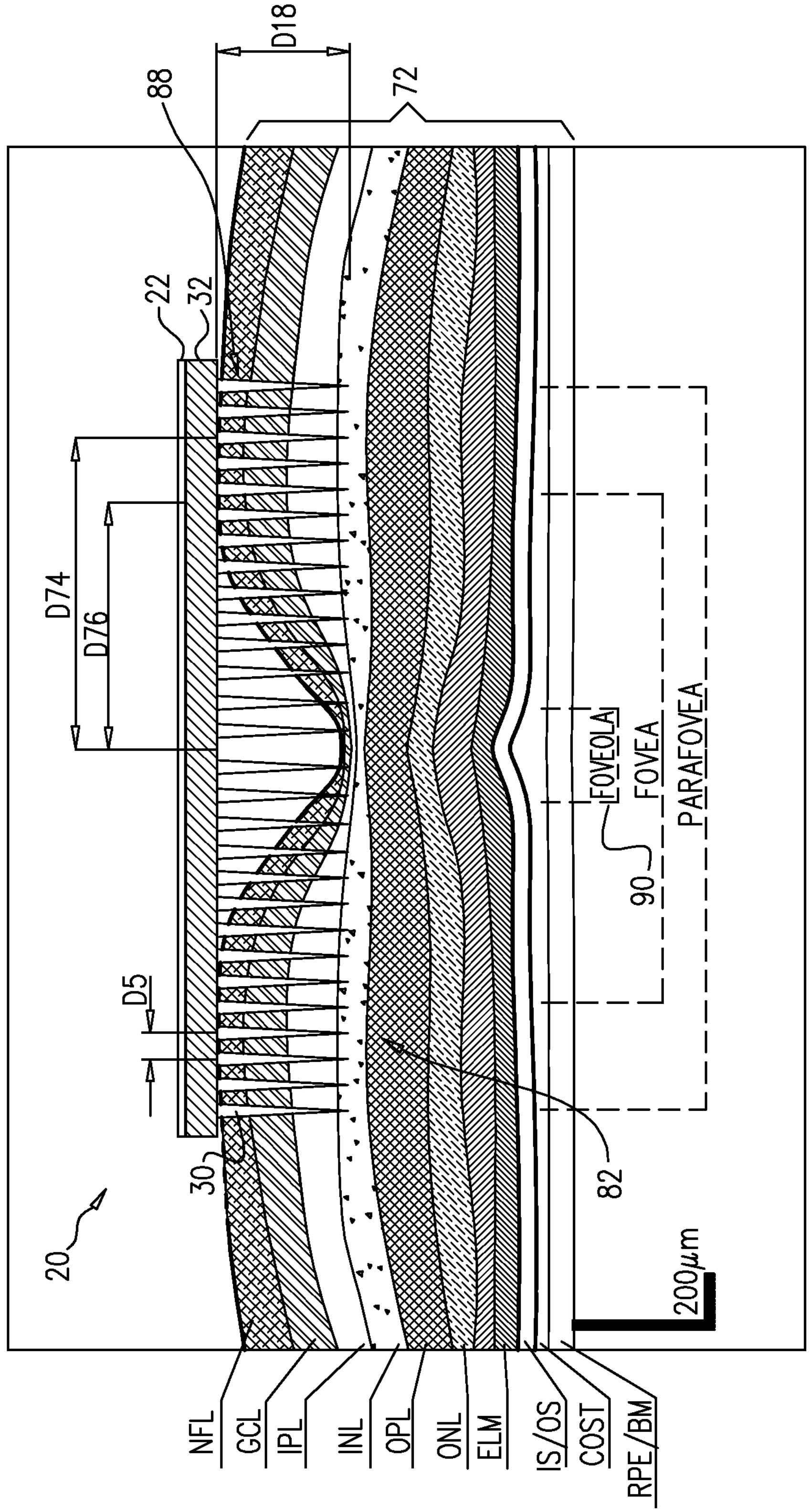
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FIG. 4B

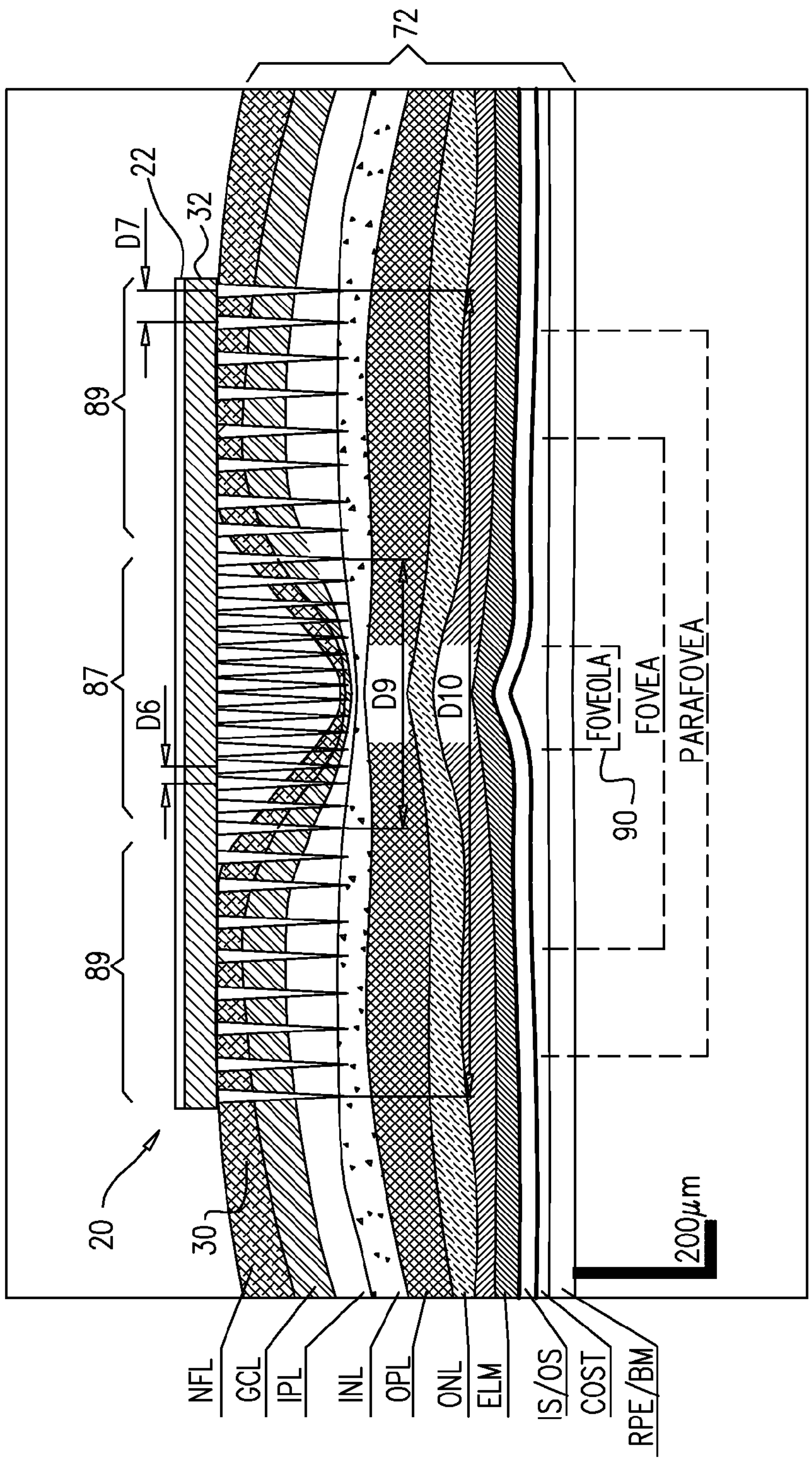
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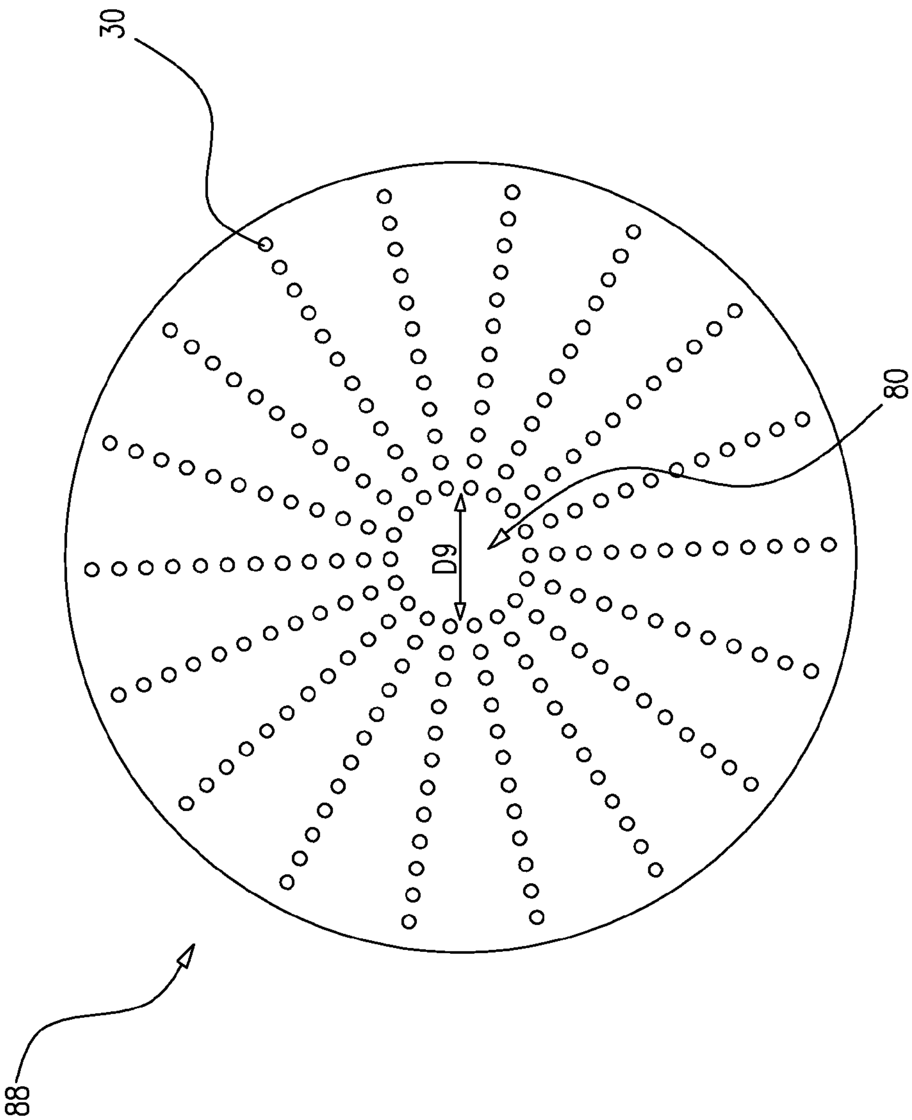
FIG. 5A



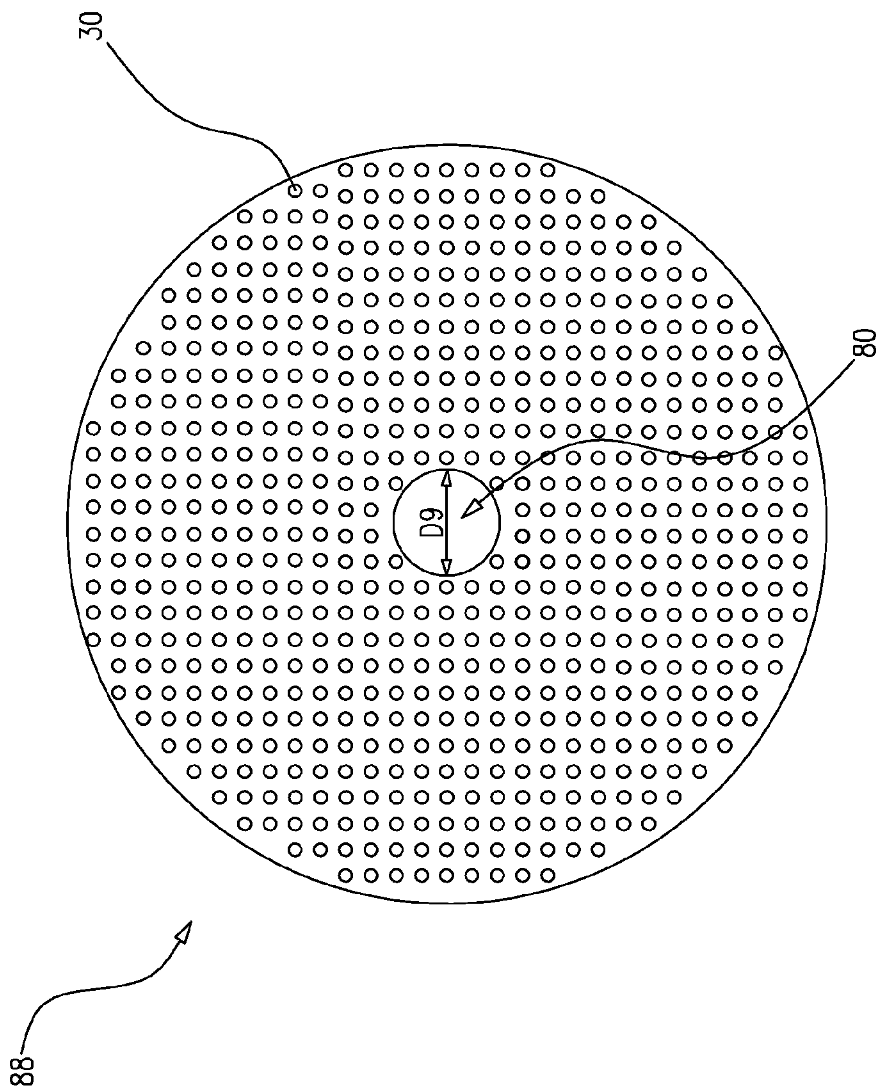


FIG. 5B

FOVEATED RETINAL PROSTHESIS

FIELD OF THE APPLICATION

Applications of the present invention relate generally to implantable medical devices, and specifically to a retinal prosthesis.

BACKGROUND OF THE APPLICATION

Retinal malfunction, due to degenerative retinal diseases, is a leading cause of blindness and visual impairment. Implantation of a retinal prosthesis is a technology for restoring some useful vision in individuals suffering from retinal-related blindness.

The retina is a multi-layered light-sensitive structure that lines the posterior, inner part of the eye. The retina contains photoreceptor cells, for example rods and cones, which capture light and convert light signals into neural signals transmitted through the optic nerve to the brain. Rods are responsible for light sensitive, low resolution black and white vision, whereas cones are responsible for sharp, high resolution color vision. Most cones lie in the fovea, which defines the center of the retina, and which allows for maximum acuity of vision. The central portion of the fovea consists of a high concentration of cones that gradually decreases at the peripheral portions of the fovea.

SUMMARY OF APPLICATIONS

For some applications, a foveated retinal prosthesis is provided comprising a space-variant photosensor imager. The retinal prosthesis is typically configured to provide at least some sharp, central, foveal vision to a visually-impaired subject. In accordance with some applications of the present invention, an intraocular device is provided which is configured to be implanted entirely in the subject's eye. The intraocular device typically comprises a space-variant photosensor array which comprises a plurality of photosensors, each photosensor configured to detect ambient photons and generate a signal in response thereto. The intraocular device additionally comprises a plurality of stimulating electrodes. Driving circuitry is coupled to the photosensors and is configured to drive the electrodes to apply electrical pulses to a retina of the eye in response to the signal from the photosensors.

Typically, the photosensor array is arranged such that a spatial density of the photosensors in a central portion of the array is greater than a spatial density of the photosensors in an outer portion of the array, resembling the structure of a native fovea of a retina. Additionally, for some applications, an intermediate portion of the photosensor array is disposed between the central portion and the outer portion of the array. Typically, a spatial density of the photosensors in the intermediate portion is between (a) the spatial density of the photosensors in the central portion and (b) the spatial density of the photosensors in the outer portion.

For some applications, the intermediate portion of the photosensor array comprises a plurality of intermediate portions, each having a different, respective spatial density of the photosensors. Thus, a stepped decrease or a smooth decrease in photosensor spatial density may be provided in alternative configurations.

For some applications the photosensor array comprises an array of at least 10 clusters of two or more photosensors. The clusters typically comprise 4-64 photosensors. For such applications, the spatial density of the photosensors in a cluster disposed in the central portion of the array is greater than the spatial density of the photosensors in a cluster disposed in the outer portion of the array.

For some applications, the plurality of stimulating electrodes are arranged in an array in a manner in which a spatial density of the electrodes in the array is constant (optionally, excluding that portion of the array which is over the foveola). For other applications, the spatial density of the electrodes in the central portion of the electrode array (optionally, excluding a portion that is over the foveola) is greater than the spatial density of the electrodes in the outer portion of the electrode array, e.g., to reduce any perceived spatial distortion of the image, whereby the inner portion of the image would appear magnified due to the foveation of the photosensor array.

There is therefore provided, in accordance with some applications of the present invention, apparatus, including an intraocular device configured to be implanted entirely in a subject's eye, the intraocular device including:

a photosensor array including a plurality of photosensors, each photosensor configured to detect ambient photons and to generate a signal in response thereto, a spatial density of the photosensors in a central portion of the array being greater than a spatial density of the photosensors in an outer portion of the array;

a plurality of stimulating electrodes; and

driving circuitry, coupled to the photosensors, and configured to drive the electrodes to apply electrical pulses to a retina of the eye in response to the signals from the photosensors.

For some applications, a spatial density of the photosensors in an intermediate portion of the array disposed between the central portion and the outer portion is between (a) the spatial density of the photosensors in the central portion and (b) the spatial density of the photosensors in the outer portion.

For some applications, the intermediate portion of the array includes a plurality of intermediate portions, each having a different, respective spatial density of the photosensors, any given intermediate portion that is closer to the central portion having a spatial density higher than that of any intermediate portion that is farther than the given intermediate portion from the central portion.

For some applications, the photosensor array includes at least two clusters of four or more photosensors, the photosensors in each cluster having a respective generally-uniform spatial density, the spatial density of the photosensors in one of the clusters that is disposed nearer the central portion of the array is greater than the spatial density of the photosensors in one of the clusters that is disposed nearer the outer portion of the array.

For some applications, the at least two clusters of four or more photosensors include at least ten clusters of four or more photosensors.

For some applications, the plurality of stimulating electrodes are arranged in an array, a spatial density of the electrodes being constant.

For some applications, the plurality of stimulating electrodes are arranged in an electrode array, a spatial density of the electrodes in a central portion of the electrode array being greater than a spatial density of the electrodes in an outer portion of the electrode array.

There is additionally provided, in accordance with some applications of the present invention, apparatus including an intraocular device configured to be implanted entirely in a subject's eye, the intraocular device including:

a photosensor array including a plurality of photosensors, each photosensor configured to detect ambient photons and to generate a signal in response thereto, an optical magnifying element coupled to the photosensor array and configured to provide a magnified image on some but less than all of the photosensors of the photosensor array;

a plurality of stimulating electrodes; and

driving circuitry, coupled to the photosensors, and configured to drive the electrodes to apply electrical pulses to a retina of the eye in response to the signals from the photosensors.

There is further provided, in accordance with some applications of the present invention, apparatus including an intraocular device configured to be implanted entirely in a subject's eye, the intraocular device including:

a photosensor array including a plurality of photosensors, each photosensor configured to detect ambient photons and to generate a signal in response thereto;

an arrangement of stimulating electrodes, a spatial density of the electrodes in a central portion of the arrangement being lower than a spatial density of the electrodes in an outer portion of the arrangement, the arrangement being such that: (a) the outer portion surrounds the central portion, and (b) the central portion is large enough to contain therewithin a circle of diameter at least 100 um; and

driving circuitry, coupled to the photosensors, and configured to drive the electrodes to apply electrical pulses to a retina of the eye in response to the signals from the photosensors.

For some applications, the spatial density of the electrodes in the central portion is zero, and the spatial density of the electrodes in the outer portion is at least 4 electrodes per mm^2.

For some applications, the outer portion of the arrangement includes at least first and second sub-portions, the second sub-portion surrounding the first sub-portion, a spatial density of the electrodes in the second sub-portion of the arrangement being lower than a spatial density of the electrodes in the first sub-portion.

For some applications, the central portion is large enough to contain therewithin a circle of diameter of 100 um.

There is also provided, in accordance with some applications of the present invention, apparatus, including:

an intraocular device configured to be implanted entirely in a subject's eye, the intraocular device including:

a photosensor array, having a center thereof, and including a plurality of photosensors, each photosensor configured to detect ambient photons and to generate a signal in response thereto;

an array of stimulating electrodes, having a center thereof, and coupled to the photosensor array; and

driving circuitry, coupled to the photosensors, and configured to drive an electrode located at a first distance from the center of the electrode array to apply electrical pulses to a retina of the eye in response to a signal from a photosensor located at a second distance from the center of the photosensor array, the first distance being greater than the second distance.

The present invention will be more fully understood from the following detailed description of embodiments thereof, taken together with the drawings, in which:

BRIEF DESCRIPTION OF THE DRAWINGS

FIG. **1** is a schematic illustration of a photosensor array for use in an implantable intraocular device, in accordance with some applications of the present invention;

FIGS. **2**A-E are schematic illustration of alternative configurations of a photosensor array for use in the implantable intraocular device of FIG. **1**, in accordance with respective applications of the present invention;

FIGS. **3**A-B are schematic illustration of an array of stimulating electrodes implanted in an eye of the subject, for use with any of the photosensor arrays shown in FIGS. **1**-**2**, in accordance with respective applications of the present invention;

FIGS. **4**A-B are schematic illustration of an array of stimulating electrodes implantable in an eye of the subject, for use with any of the photosensor arrays shown in FIGS. **1**-**2**, in accordance with respective applications of the present invention; and

FIGS. **5**A-B are schematic illustrations of a bottom view of an array of stimulating electrodes implantable in an eye of the subject, for use with any of the photosensor arrays shown in FIGS. **1**-**2**, in accordance with respective applications of the present invention.

DETAILED DESCRIPTION OF APPLICATIONS

Reference is made to FIG. **1**, which is a schematic illustration of a photosensor array **22** configured for use as part of an implantable intraocular device **20**, in accordance with some applications of the present invention. Photosensor array **22** comprises a plurality of photosensors **24**, each photosensor **24** configured to detect ambient photons and to generate a signal in response thereto. Driving circuitry **32**, coupled to photosensors **24**, drives a plurality of stimulating electrodes **30** to apply electrical pulses to a retina of the eye in response to the signal from the photosensors.

As shown schematically in FIG. **1**, photosensor array **22** is arranged such that a spatial density of photosensors **24** in a central portion **26** of array **22** is greater than a spatial density of photosensors **24** in an outer portion **28** of array **22**. As shown, a distance D1 between two photosensors **24** disposed in central portion **26** is smaller than a distance D4 between two photosensors **24** disposed in outer portion **28**. For example, D1 is typically greater than 2 um and/or less than 100 um, e.g., greater than 4 um and/or less than 50 um. D4 is typically greater than 40 um and/or less than 1000 um, e.g., greater than 100 um and/or less than 500 um (e.g., 300 um). D4 divided by D1 is typically at least 2 (e.g., at least 4) and/or less than 200.

For some applications, the spatial density of the photosensors in an intermediate portion **34** of the array disposed between central portion **26** and outer portion **28** is between (a) the spatial density of the photosensors in central portion **26** and (b) the spatial density of the photosensors in outer portion **28**. For example, a distance D2 between photosensors in intermediate portion **34** is between D1 and D4.

Photosensor array **22** may similarly be arranged to have a plurality of intermediate portions **34** and **36**, each having a different, respective spatial density of photosensors **24**. In such an arrangement, any given intermediate portion **34** that is closer to central portion **26** has a spatial density higher than that of any intermediate portion **36** that is farther than given intermediate portion **34** from central portion **26**. Photosensor array **22** may be arranged to have 2, 3, 4-6, 7-10, or more intermediate portions. (Two intermediate portions **34** and **36** are shown in FIG. **1**.)

FIG. **2**A is a schematic illustration of photosensor array **22**, in which photosensors **24** are arranged in concentric rings, in accordance with some applications of the present invention. As shown in the figures of the present patent application, the rings of photosensors are square rings, although the scope of the present invention includes the use of concentric rectangular, circular, hexagonal, and elliptical rings, as well as concentric rings of other shapes. Examples of hexagonal and circular photosensor arrays are shown in FIGS. **2**D-E (respectively).

Each ring of photosensors **24** shown in FIG. **2**A has the photosensors thereof disposed with a given distance D13 separating adjacent photosensors in the same ring. Photosensor array **22** as shown in FIG. **2**A is characterized in that the distance D13 between photosensors in a ring closer to central portion **26** is smaller than the distance D14 between photosensors in a ring farther from central portion **26**. In the application shown in FIG. **2**A, successive rings going from central portion **26** toward outer portion **28** have gradually increasing, and typically monotonically increasing, distances between photosensors in each successive ring.

Alternatively or additionally, the distance between successive rings increases (typically monotonically) from a smaller distance D11, nearer central portion **26**, to a larger distance D12, farther from central portion **26**.

As shown in FIG. **2**A and other figures, for some applications the rings of photosensors **24** may surround a central core **54** of photosensors, which are not arranged as a ring. Central core **54** typically comprises 4-100 photosensors **24**. For some applications, the photosensors in central core **54** are spaced from each other by a distance D15 of 4-30 um, and/or central core **54** itself has a length D16 of 16-300 um as its longest dimension. For some applications, D16 is greater than 300 um (e.g., as shown in FIG. **2**C).

For some applications, the number of photosensors **24** in each successive ring is constant, even though the perimeter of the ring increases. Alternatively, the number of photosensors increases, but not as fast as the perimeter of the ring. Still further alternatively, the number of photosensors in each increases as fast as the perimeter of the ring (i.e., a ring having twice as many photosensors as a more central ring also has twice the perimeter of the more central ring), however the space between successive rings increases (e.g., from D11 to D12 as shown).

As appropriate based on the amount of photosensor foveation desired in a given design, the increase in ring spacing (e.g., D11 to D12) and/or the increase in intra-sensor spacing (e.g., D13 to D14) may follow, for example, an arithmetic progression (k, 2 k, 3 k . . .) or a geometric progression (1, k, k^2, k^3 . . .). Typically, arithmetic progression spacing produces gradual spatial distortion of the image, which generally allows for rapid cognitive adjustment of the subject to a new implant.

FIG. **2**B is a schematic illustration of photosensor array **22**, in which photosensors **24** are arranged in concentric rings, having geometric or another progression spacing, in accordance with another application of the present invention. Typically, in applications in which photosensors **24** are arranged in concentric rings having geometric progression spacing, array **22** is particularly space efficient. This is generally due to the high spatial density of photosensors **24** in the central portion of the array and a rapid decrease in spatial density of photosensors **24** in the outer portion of the array. The apparatus of FIG. **2**B is generally similar to that of FIG. **2**A, except for differences as noted herein.

FIG. **2**C is a schematic illustration of photosensor array **22**, in which photosensors **24** are arranged in clusters (e.g., 1, 1, 2, 2 . . .), in accordance with another application of the present invention. Typically, photosensor array **22** comprises at least two clusters of four or more photosensors **24**. The photosensors in each cluster typically have a respective generally-uniform spatial density, and the spatial density of the photosensors in a cluster **52** that is disposed nearer central portion **26** of the array is greater than the spatial density of the photosensors **24** in a cluster **50** that is disposed nearer outer portion **28** of array **22**.

The clusters of photosensors **24** as shown in FIG. **2**C are two-dimensional, thus creating array **22** not just with concentric rings of photosensors that have respective densities, but with two-dimensional regions of the array that have particular spatial densities.

Typically, arrangement of photosensors **24** in clusters creates an increased area with constant pixel spacing in central portion **26** of the array, resulting in reduced spatial distortion of the image.

Reference is made to FIGS. **1**-**2**E. For some applications, a size of photosensors **24** is varied across array **22**. For example, the size of photosensors **24** in central portion **26** of array **22** may be smaller than the size of photosensors **24** in outer portion of array **22**. Variable-sized photosensors may be used in combination with a space-variant array or, alternatively, with an array having constant spacing of photosensors. Alternatively or additionally, the signals generated by multiple photosensors **24** in outer portion **28** of array **22** are used to regulate current delivered from a smaller number of electrodes, e.g., a single electrode (which may be useful in low-light conditions, for example).

Alternatively, for some applications, the array of photosensors is arranged to provide first and second portions, e.g., left and right portions, rather than central and outer portions. For such applications, the photosensor array is arranged such that a spatial density of the photosensors in the first portion of the array is greater than a spatial density of the photosensors in the second portion of the array (application not shown).

Reference is made to FIGS. **3**A and **3**B, which are schematic cross-sectional illustrations of intraocular device **20**, comprising photosensor array **22** (e.g., as described hereinabove with reference to any of the figures) and an array **88** of stimulating electrodes **30** that are epiretinally implanted in the retina **72** of the subject, in accordance with some applications of the present invention.

Intraocular device **20** as shown in FIGS. **3**A and **3**B comprises an arrangement of stimulating electrodes **30**, in which a spatial density of the electrodes in a central portion **80** of the arrangement is lower than a spatial density of the electrodes in an outer portion **82** of the arrangement. In this arrangement, outer portion **82** surrounds central portion **80**.

Central portion **80** typically has a length (e.g., a diameter) D9 of 50-1000 um, e.g., 100-500 um, so as to generally cover foveola **90**. In any case, central portion **80** is at least large enough to contain therewithin a circle of diameter D9 of 50-1000 um, e.g., a circle of diameter 100-500 um, e.g., a circle of diameter 100-300 um.

Central portion **80** is typically placed over the foveola **90** of the patient's retina, such that typically no electrodes, or only a small number of electrodes are placed in the foveola (e.g., within but near the edge of the circle having diameter D9). In any case, the spatial density of electrodes in central portion **80** that are placed in the foveola is lower than the spatial density of electrodes in outer portion **82** that are placed in retinal tissue outside of the fovea or parafovea outside of the foveola. For example, the spatial density of electrodes in central portion **80** that are placed in the foveola may be zero if, as shown in FIGS. **3**A and **3**B, central portion **80** has no electrodes. For some applications, the spatial density of the electrodes in the central portion is zero, and the spatial density of the electrodes in the outer portion is at least 4 electrodes per mm^2 (for example, at least 10 electrodes per mm^2, and/or less than 400 or less than 100 electrodes per mm^2).

Alternatively, central portion **80** comprises any number of electrodes (e.g., as shown in FIGS. **4**A-B) and implantable intraocular device **20** is configured such that driving circuitry **32** does not drive stimulating currents into the electrodes that are located in central portion **80**. For such applications, electrodes **30** in central portion **80** may function to anchor device **20** to the retina and not to drive stimulating currents into the retina.

Further alternatively, central portion **80** that is placed over foveola **90** does not comprise electrodes, but rather comprises an anchoring element, e.g., a metallic tack, configured to facilitate anchoring of device **20** to the retina of the subject.

The retina includes a number of identified layers, each having its own properties. These layers include the nerve fiber layer (NFL), ganglion cell layer (GCL), inner plexiform layer (IPL), inner nuclear layer (INL), outer plexiform layer (OPL), outer nuclear layer (ONL), external limiting membrane (ELM), photoreceptor inner segments (IS) and outer segments (OS), cone photoreceptor outer segment tips (COST), and retinal pigment epithelium/Bruch's membrane (RPE/BM). Electrodes **30** typically have a length D18 of at least 50 um and/or less than 500 um, in order to facilitation penetration of the retina. For some applications of the present invention it is intended for electrodes **30** to penetrate the retina and stimulate a layer that is largely not present in the foveola but which is relatively thick in the surrounding fovea and parafovea (e.g., the inner nuclear layer and/or the ganglion cell layer). For these applications, electrodes **30** are typically arranged to provide central portion **80** as described, so as not to provide stimulation intended to generate perception of an image on a part of the retina (the foveola) that does not have significant ganglionic processing.

Typically, as shown in FIG. **3**A, stimulating electrodes **30** are arranged in an array, a spatial density of electrodes in outer portion **82** being constant (e.g., 100 um). For example, a distance D5 between adjacent electrodes is typically greater than 10 um and/or less than 500 um. For applications in which the array of electrodes **30** is arranged as a square or a rectangular array, a longest row or column of the array typically has a length D10 greater than 1 mm and/or less than 6.0 mm, e.g., 2-4 mm, so as to generally cover the parafovea. For other arrangements of the electrodes (e.g., concentric circles of electrodes as shown in the bottom view of electrode arrays in FIGS. **5**A-B), such values for D10 represent a furthest distance between two electrodes in the array (e.g., a diameter of the circle).

For some applications, an optical magnifying element **70** comprising a single lens (as shown) or a plurality of lenses (e.g., as a telescope, configuration not shown) is coupled to photosensor array **22** and provides a magnified image on some but less than all of photosensors **24** of photosensor array **22**. Typically, element **70** is disposed a distance D8 of at least 1 mm and/or less than 30 mm (e.g., less than 15 mm) from photosensor array **22**. This arrangement provides magnification of the image being viewed, may be used in combination with, or in the absence of, a variation in spatial density of the photosensors as described hereinabove.

Reference is made to FIG. **3**B. For some applications, outer portion **82** of the arrangement comprises at least first and second sub-portions **84** and **86**, the second sub-portion surrounding the first sub-portion. The spatial density of the electrodes in second sub-portion **86** of the arrangement is lower than the spatial density of the electrodes in first sub-portion **84**, e.g., in order to provide higher spatial stimulation resolution in portions of the retina having the ability to perform more ganglionic processing of incoming visual information. For example, electrodes **30** in sub-portion **84** may be separated by a distance D6 that is at least 10 um and/or less than 100 um, while electrodes **30** in sub-portion **86** may be separated by a distance D7 that is at least 300 um and/or less than 500 um.

Reference is made to FIGS. **4**A-B, which are schematic illustrations of array **88**, in accordance with respective applications of the present invention. For some applications, array **88** does not comprise a portion **80** that does not have electrodes as described hereinabove with reference to FIGS. **3**A-B. As shown in FIG. **4**A, stimulating electrodes **30** are arranged in array **88** such that a spatial density of electrodes across the array is constant (e.g., with an interelectrode spacing of 100 um). Alternatively, as shown in FIG. **4**B, array **88** comprises a central portion **87** and an outer portion **89**, and a spatial density of the electrodes in central portion **87** is greater than the spatial density of the electrodes in outer portion **89** of array **88**.

Reference is made to FIGS. **5**A-B, which are schematic illustration of bottom views of array **88** of stimulating electrodes **30** implantable in an eye of the subject, for use with any of the photosensor arrays shown in FIGS. **1-2**, in accordance with respective applications of the present invention. As shown in FIGS. **5**A-B, for some applications, arrays **88** comprises a central portion **80** which is typically at least large enough to contain therewithin a circle of diameter D9 of 50-1000 um, e.g., a circle of diameter 100-500 um, e.g., a circle of diameter 100-300 um.

Reference is made to FIGS. **1-5**B. For some applications, photosensor array **22** and array **88** of electrodes **30** have a similar spatial distribution such that the location of each photosensor **24** on array **22** corresponds to a location of a single electrode **30** (e.g., each photosensor is located above a corresponding electrode). Typically in such applications, perceived spatial distortion of the image is reduced.

Alternatively, photosensor array **22** and array **88** of electrodes **30** have a different spatial distribution, such that some or all photosensors **24** and electrodes **30** do not have a one-to-one spatial correspondence (e.g., each photosensor is not located above each corresponding electrode). For some such applications, photosensor array **22** maps a signal that is sensed at the center of array **22** to cause stimulation at a radially displaced site on electrode array **88** (i.e., an electrode that is located farther from the center of array **88**). For example, device **20** may be configured such that a signal received by photosensors **24** in central portion **26** of array **22** causes driving of an electrode located in outer portion **82** of array **88**. Thereby, current is generally not applied to central portion **80** of array **88** (e.g., current is largely not applied to foveola **90**). As additionally shown by way of example in FIG. **4**A, an electrode located at a first distance D74 from a center of electrode array **88** is configured to apply electrical pulses to the retina in response to a signal from a photosensor in array **22** located at a second distance **76** from a center of photosensor array **22**. As shown, first distance D74 is greater than second distance D76.

It is noted that electrodes **30** may be arranged in an array that is square, rectangular, circular, elliptical, or hexagonal, or in other shapes.

It will be appreciated by persons skilled in the art that the present invention is not limited to what has been particularly shown and described hereinabove. Rather, the scope of the present invention includes both combinations and subcombinations of the various features described hereinabove, as well as variations and modifications thereof that are not in the prior art, which would occur to persons skilled in the art upon reading the foregoing description.

The invention claimed is:

1. Apparatus comprising an intraocular device configured to be implanted entirely in a subject's eye, the intraocular device comprising:

a photosensor array comprising a plurality of photosensors, each photosensor configured to detect ambient photons and to generate a signal in response thereto;

an arrangement of stimulating electrodes, a spatial density of the electrodes in a central portion of the arrangement being lower than a spatial density of the electrodes in an outer portion of the arrangement, the arrangement being such that: (a) the outer portion surrounds the central portion, and (b) the central portion is large enough to contain therewithin a circle of diameter of at least 100 microns and has a diameter of less than 1000 microns; and

driving circuitry, coupled to the photosensors, and configured to drive the electrodes to apply electrical pulses to a retina of the eye in response to the signals from the photosensors.

2. The apparatus according to claim **1**, wherein the spatial density of the electrodes in the central portion is zero, and wherein the spatial density of the electrodes in the outer portion is at least 4 electrodes per mm^2.

3. The apparatus according to claim **2**, wherein the spatial density of the electrodes in the outer portion is between 10 and 100 electrodes per mm^2.

4. The apparatus according to claim **1**, wherein the outer portion of the arrangement comprises at least first and second sub-portions, the second sub-portion surrounding the first sub-portion, a spatial density of the electrodes in the second sub-portion of the arrangement being lower than a spatial density of the electrodes in the first sub-portion.

5. The apparatus according to claim **4**, wherein the electrodes in the first sub-portion are separated by a distance of 10-100 microns.

6. The apparatus according to claim **4**, wherein the electrodes in the second sub-portion are separated by a distance of 300-500 microns.

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